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LETTER TO THE EDITOR

The spectrum of 1ES0229 + 200 and the cosmic infrared background

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ABSTRACT

Aims. We reexamine the implications of the recent HESS observations of the blazar 1ES0229+200 for constraining the extragalactic mid-infrared background radiation.
Methods. We examine the effect of γ-ray absorption by the extragalactic infrared radiation on predicted intrinsic spectra for this blazar and compare our results with the observational data.
Results. We find agreement with our previous results on the shape of the infrared spectral energy distribution, contrary to the recent assertion of the HESS group. Our analysis indicates that 1ES0229+200 has a very hard intrinsic spectrum with a spectral index between 1.1 ± 0.3 and 1.5 ± 0.3 in the energy range between $\sim$0.5 TeV and $\sim$15 TeV.
Conclusions. Under the assumptions that (1) the models of Stecker et al. (2006, ApJ, 648, 774) as derived from numerous detailed infrared observations are reasonable, and (2) spectral indexes in the range $1 < \Gamma < 1.5$ are obtainable from relativistic shock acceleration under the astrophysical conditions extant in blazar flares (Stecker et al. 2007, ApJ, 667, L29), the fits to the observations of 1ES0229+200 using our previous infrared spectral energy distributions are consistent with both the infrared and γ-ray observations. Our analysis presents evidence indicating that the energy spectrum of relativistic particles in 1ES0229+200 is produced by relativistic shock acceleration, producing an intrinsic γ-ray spectrum with index $1 < \Gamma < 1.5$ and with no evidence of a peak in the spectral energy distribution up to energies $\sim$15 TeV.

Key words. infrared: general – radiation mechanisms: general – galaxies: BL Lacertae objects: individual: 1ES0229+200

1. Introduction

Shortly after the first strong γ-ray blazar 3C279 was discovered by the EGRET detector aboard the Compton Gamma Ray Observatory (CGRO), Stecker et al. (1992) proposed that the study of the spectra of such sources could be used to probe the intergalactic infrared (IR) radiation. At that time, there were no actual direct observations of the diffuse extragalactic IR background or extensive observations of the sources of such radiation. The idea was to look for the effects of photon–photon annihilation interactions into electron–positron pairs. The cross section for this process is exactly determined; it can be calculated using quantum electrodynamics (Breit & Wheeler 1934). Thus, in principle, if one knows the emission spectrum of an extragalactic source at a given redshift, one can determine the column density of photons between the source and the Earth.

In the last 15 years, great advances have been made in extragalactic IR astronomy. The diffuse background at wavelengths not totally dominated by galactic or zodiacal emission has been measured by the Cosmic Background Explorer (COBE). In addition, there have been extensive observations of IR emission from galaxies themselves, whose total emission is thought to make up the cosmic IR background (see review by Hauser & Dwek 2001). The latest extensive observations have been made by the Spitzer satellite. It is thus appropriate to use a synoptic approach combining the TeV γ-ray observations with the extragalactic IR observations, in order to best explore both the TeV emission from blazars and the diffuse extragalactic IR radiation.

Aharonian et al. (2007) have recently observed the spectrum of the BLLac object 1ES0229+200 up to an energy $\sim$15 TeV with the High Energy Spectroscopic System (HESS). Then, by assuming that the intrinsic spectral index of this source is greater than 1.5, they drew conclusions regarding wavelength dependence and flux of the mid-IR extragalactic background radiation. Their conclusions regarding the mid-IR extragalactic background radiation appear to disfavor the results of the extensive semi-empirical calculations of the extragalactic IR background spectrum given by Stecker et al. (2006, hereafter SMS).

In this paper, we will reexamine the assumptions and conclusions of Aharonian et al. (2007) and show that the observations of 1ES0229 are fully consistent with the diffuse IR background spectrum obtained by SMS. Furthermore, we will show that 1ES0229+200 is an example of a set of blazars that exhibit very hard spectra indicative of relativistic shock acceleration.

2. The diffuse extragalactic IR background

Various calculations of the extragalactic IR background have been made (Stecker et al. 1977; Malkan & Stecker 1998, 2001; Totani & Takeuchi 2002; Kneiske et al. 2004; Primack et al. 2005; SMS). Of these models, the most empirically based are those of Malkan & Stecker (1998, 2001), Totanti & Takeuchi (2002) and SMS. The SMS calculation includes input from the latest Spitzer observations. Since the largest uncertainty in these calculations arises from the uncertainty in the temporal evolution

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of the star formation rate in galaxies, SMS assumed two different evolution models, viz., a "baseline" model and a "fast evolution" model. These models produced similar wavelength dependences for the spectral energy distribution of the extragalactic IR background, but gave a difference of roughly 30–40% in overall intensity.

The empirically based calculations mentioned above include the observationally based contributions of warm dust and emission bands from polycyclic aromatic hydrocarbon (PAH) molecules and silicates, which have been observed to contribute significantly to galaxy emission in the mid-IR (e.g., Lagache et al. 2004). These components of galactic IR emission have the effect of partially filling in the "valley" in the mid-IR spectral energy distribution between the peak from starlight emission and that from dust emission. In contrast, the model of Primack et al. (2005) exhibits a steep mid-IR valley, which is in direct conflict with lower limits obtained from galaxy counts at 15 μm (Altieri et al. 1999; Elbaz et al. 2002).

3. Intrinsic spectra of blazars from theoretical considerations

The key difference between our analysis and that of Aharonian et al. (2007) is their assumption that the intrinsic spectral indexes of blazars cannot be greater than 1.5. Stecker et al. (2007, hereafter SBS) have shown that spectral indexes between 1 and 1.5 are obtainable from relativistic shock acceleration. They list three blazars with intrinsic spectral indexes between ~1 and ~1.5 in the energy range between 0.2 TeV and 2 TeV. Their simulations indicate that a range of spectral indexes can be produced by relatvistic shocks, depending on the conditions in the individual shocks.

In fact, recent observations of an extreme MeV γ-ray blazar at a redshift of ~3 by *Swift* (Sambruna et al. 2006) and the powerful γ-ray quasar PKS 1510-089 at a redshift of 0.361 by *Swift* and *Suzaku* (Kataoka et al. 2007) both exhibited power-law spectra in the hard X-ray range that had indexes less than 1.5, implying electron spectra with indexes less than the value of 2 usually considered for shock acceleration. In addition, the quasar IGR J22517+2218, at a redshift of 3.668, has been observed with *IBIS/INTEGRAL* to have a spectral index of 1.4 ± 0.6 in the 20–100 keV hard X-ray energy range (Bassani et al. 2007). Spectra in the hard X-ray range do not suffer intergalactic absorption so there is no ambiguity concerning their spectral indexes.

4. The observed spectrum of 1ES0229+200 and its derived intrinsic spectrum

The BL Lac object 1ES0229+200 was predicted to be an observable TeV source with a TeV flux of $\sim 10^{-12}$ cm^{-2} s^{-1} by Stecker et al. (1996). It was detected by Aharonian et al. (2007) at a flux level of $\sim 0.94 \times 10^{-12}$ above 0.58 TeV. Aharonian et al. (2007) have measured the spectrum of the blazar 1ES0229+200 at energies between 0.5 TeV and ~15 TeV. This blazar lies at a redshift of 0.14 (Schachter et al. 1993). This redshift, together with the spectral observations, implies a very hard intrinsic spectrum for the source.

According to the observations of Aharonian et al. (2007), the blazar 1ES0229+200 has an observed spectral index of 2.50. In their analysis, Aharonian et al. chose to "deabsorb" their data points using the results of various optical depth calculations and to fit a simple power-law spectrum to the results. Using estimated optical depths from SMS, they gave best-fit power-law spectral indexes of 0.1 ± 0.3 for the fast evolution case and 0.6 ± 0.3 for the baseline case. We have done a reanalysis using their method and find spectral indexes of 0.2 ± 0.3 and 0.8 ± 0.3 for the SMS fast evolution and baseline models, respectively. The small difference in the results can be attributed to Aharonian et al. using interpolated optical depths, as SMS did not provide the results at the specific redshift of 1ES0229+200. We here calculated the optical depths for $z = 0.14$ exactly, for both the fast evolution and baseline evolution models of SMS.

In this paper, we will adopt a different method for analyzing the intrinsic spectrum of 1ES0229+200, one which we feel is superior to the above approach. Aharonian et al. (2007) chose to force a power-law fit to the deabsorbed data points. We choose here to assume an intrinsic power-law spectrum emitted by the source and then apply a correction for optical depth. We then compare the resulting spectrum with the actual observed spectrum. Because of the nonlinear nature of the energy dependence of the optical depth, we do not expect that the observed spectrum will have a power-law form.

Using the formulas given by Stecker & Scully (2006), we predict an intrinsic spectral index for 1ES0229+200 of 1.11 for the fast evolution model spectral energy distribution and 1.45 for the baseline model spectral energy distribution in the 0.2 to 2 TeV energy range. This intrinsic power-law spectrum, derived for the 0.2 TeV to 2 TeV energy range, is then assumed to be extended to ~15 TeV. Such a spectrum with an index between 1 and 1.5 can be obtained from relativistic shock acceleration, as discussed in the previous section. We have then calculated the form of the resulting spectrum that would be observed at Earth, by taking account of the absorption predicted by both the baseline and fast evolution models of SMS.

Thus, the observed spectrum is fixed to be of the form $K_{\rm FE} E^{-1.11} e^{-\tau_{\rm FE}(E;z=0.14)}$ and $K_{\rm B} E^{-1.45} e^{-\tau_{\rm B}(E;z=0.14)}$ for the fast evolution and baseline models, respectively, where τ is the optical depth of the universe to γ-rays originating at a redshift of 0.14, calculated according to SMS. We employ a Levenberg-Marquardt nonlinear least squares method to fit this form of the spectrum to the observed data. In each case, the single parameter of the fit is the normalization coefficient, K. The Levenberg-Marquardt method minimizes χ^2 to best fit a nonlinear function to the observational data. For the fast evolution model, $K_{\rm FE} = 10^{-10.80}$ cm^{-2} s^{-1} TeV^{-1} with E in TeV; for the baseline model, $K_{\rm B} = 10^{-11.13}$ in the same units. The resulting spectra are plotted along with the data in Fig. 1. As can be seen in Fig. 1, these curves show excellent consistancy with the observational data obtained by the HESS group for 1ES0229 + 200. Indeed, the χ^2 vlaues obtained are 3.3 for the baseline fit and 5.7 for the fast evolution fit with 7 degrees of freedom.

5. Conclusions and discussion

Aharonian et al. (2007), by assuming that blazar spectra have spectral indexes $\Gamma > 1.5$, concluded that the mid-IR SED must have a wavelength dependence steeper than λ^{-1}, in their terminology $\lambda^{-\alpha}, \alpha > 1.1 \pm 0.25$ in the wavelength range between 2 μm and 10 μm. On the contrary, galaxy emission models that take into account emission by warm dust and PAH and silicate emission in the mid-IR, as well as direct mid-IR observations of galaxy spectra, give values for α in the range between ~0.7 and ~0.8 (Spinoglio et al. 1995; Xu et al. 2001). These values are consistent with the 2–10 μm diffuse background spectral energy distribution given in the semi-empirical SMS models. Such

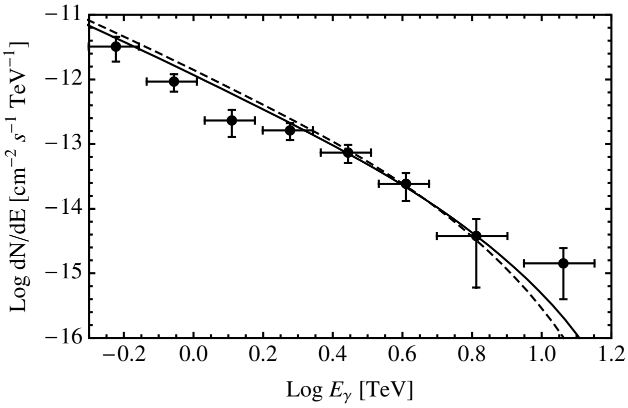

Fig. 1. The observed and calculated spectrum of 1ES0029+200. Data are from Aharonian et al. (2007). The vertical bars are statistical errors; the horizontal bars are the energy bins. The calculations of the spectra are as described in the text. The solid line is the best fit with τ given for the baseline model of SMS; the dashed line is the best fit with τ given for the fast evolution model of SMS.

values lead to an energy dependence for the γ-ray optical depth that is consistent with that obtained by both Totani & Takeuchi (2002) and SMS. This result is also supported by the lower limit on the 15 μm diffuse background flux obtained by galaxy counts of 3.3 ± 1.3 nW m^{-2} sr^{-1} (Altieri et al. 1999), which, under the conservative assumption that 80% of the mid-IR flux is resolved out (SMS), yields a value for the total diffuse background flux at 15 μm of 4.1 ± 1.6 nW m^{-2} sr^{-1}, higher than the upper limit of 3.1 nW m^{-2} sr^{-1} derived by Aharonian et al. (2007) under the assumption that $\Gamma > 1.5$.

Under the assumptions that (1) the spectral energy distribution models of SMS are reasonable, as derived from numerous detailed IR observations, and (2), as shown by SBS, spectral indexes in the range $1 < \Gamma < 1.5$ are obtainable from relativistic shock acceleration under the astrophysical conditions extant in blazar flares, the fits to the HESS TeV observations of 1ES0229+200 using the SMS IR SEDs are consistent with both the IR and γ-ray observations.

The SBS simulations indicate with specific test runs that electron spectra with asymptotic spectral indexes between 1.26 and 1.62 can be obtained from acceleration by relativistic shocks with bulk Lorentz factors between 10 and 30, and these electrons can then Compton scatter to produce γ-ray spectra with indexes $\sim$1.1 and $\sim$1.3. The simulations show that larger bulk Lorentz factors lead to flatter spectra. Such Lorentz factors of 50 or more have been implied from studies of specific flares in BL Lac objects (Konopelko et al. 2003; Bagelman et al. 2007) so that the existence of highly relativistic shocks in such sources with indexes as flat as $\sim$1 is not unreasonable.

For the SMS fast evolution spectral energy distribution, the γ-ray index obtained is 1.11 and for the baseline spectral energy distribution, the index obtained is 1.45. Our analysis thus presents evidence for relativistic shock acceleration in 1ES0229+200 that results in a very hard intrinsic γ-ray spectrum with no evidence of a peak in the γ-ray spectral energy distribution up to energies $\sim$10 TeV. Unfortunately, there are no simultaneous observations at other wavelengths that can be used to model the flare that occurred in 1ES0229+200 and, in any case, TeV orphan flares have been observed in other BL Lac objects. However, we note that hard X-ray spectra have been seen in other sources, as discussed in Sect. 3. We also note that SBS have derived spectra for three other BL Lac objects at redshifts between 0.18 and 0.19 with indexes between 1 and 1.5, viz., 1ES1218+30, 1ES1101-232, and 1ES0347-121. It therefore appears that a whole class of blazars or blazar flares may exhibit the hard-spectrum characteristics of relativistic shock acceleration.

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